REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01/04/2003	Final	January 1, 2001 - December 31, 2002

4. TITLE AND SUBTITLE
Marginal Sea-Open Ocean Exchange

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-01-1-0165

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Michael A. Spall

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Woods Hole Oceanographic Institution
360 Woods Hole Road
Woods Hole, MA 02543

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research Regional Office Boston
495 Summer Street, Room 627
Boston, MA 02210-2109

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

A variety of analytic and numerical models are developed in order to explore the wind-and-buoyancy-forced circulation in marginal seas and their exchange with the open ocean. The sensitivity of the solutions to key nondimensional parameters are described, with focus on the role of small-scale mixing and eddies. Cases of single strait (Mediterranean Sea, Adriatic Sea) and multiple strait (Sea of Japan, Caribbean Sea) marginal seas are explored.

15. SUBJECT TERMS
marginal seas, thermohaline circulation, numerical models, buoyancy forcing

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Michael A. Spall
U	U	U	UU	4	19b. TELEPHONE NUMBER *(Include area code)* (508)289-3342

FINAL REPORT for ONR Grant No. N00014-01-1-0165
PROJECT TITLE: Marginal Sea - Open Ocean Exchange

Michael A. Spall, Principal Investigator
Woods Hole Oceanographic Institution
Physical Oceanography Department, M.S. 21
360 Woods Hole Road, Woods Hole, MA 02543-1541
Tel: (508) 289-3342 Fax: (508) 457-2181
e-mail: mspall@whoi.edu

LONG TERM GOALS

The long-term goal of this project is to contribute to our understanding of the circulation, exchange, and environment between marginal seas and the open ocean.

The objective of this work is to better understand how the exchange between a marginal sea and the open ocean, and the circulation within the marginal sea, depend on the wind- and buoyancy-forcing in the marginal sea and open ocean. Areas of focus include: mass and heat flux through the straits; circulation pathways in the marginal sea; regions of large air-sea heat flux; regions of deep mixing and regions of downwelling in the marginal sea.

APPROACH

The approach is to develop analytic and numerical models that demonstrate how the exchange between the marginal sea and the open ocean, and the circulation within the marginal sea, depend on buoyancy- and wind-forcing and small-scale mixing. The models are applied to the circulations in the Japan / East Sea, the Indonesian throughflow, and generic marginal seas. The basin configurations are necessarily idealized in order to permit simple representations of the important geometrical and physical parameters, and to determine their influences on the quantities of interest. The overall objective is to provide simple physical explanations for the dominant aspects of the observed circulations in the marginal seas. Numerical models are also applied to realistic configurations to test the theoretical results in a more complete context.

WORK COMPLETED

These ideas have been applied to three regions: the Indonesian throughflow, the Japan / East Sea (JES), and generic marginal seas. In each case, analytic and numerical models have been developed for idealized configurations representative of these regions. For multiple strait marginal seas (or porous boundaries), integral constraints have also been derived that relate the net circulation around the island, and its baroclinic structure, to the atmospheric forcing and the island configuration.

For the case of the Indonesian throughflow, the analytic model shows that the upper ocean zonal current in the eastern Indian Ocean impinges on the west coast of Australia and forms the poleward Leeuwin Current. Circulation integrals around the island are then used to infer the influences of this eastern boundary current on the baroclinic exchange between the Indian and Pacific Oceans.

Comparisons are made between the analytic predictions and results found in a two-layer primitive equation model.

Different analytic and numerical models of the JES have been developed to determine the influence of wind-forcing and buoyancy loss in the JES on the circulation within the JES and the exchange with the Pacific Ocean. Estimates of the exchange rate and regions of downwelling have been derived from the analytic model and compared with the numerical model.

Numerical and analytic models are also applied to the thermohaline circulation in a marginal sea with and without topography and subject to a net buoyancy loss in the interior. The marginal sea is connected to an open ocean through a narrow strait.

Numerical and analytic models have also been developed for the flow through a ``porous" boundary, intended to represent a region of many islands or channels and gaps, such as the mid-Atlantic Ridge or the Caribbean Archipelago.

RESULTS

For cases in which the marginal sea is connected to the open ocean by more than one strait, exchange with the open ocean is most strongly influenced if the heat loss takes place along the west coast of the island separating the marginal sea from the open ocean, as found near western Australia and western Japan. There is generally close agreement between the analytic and numerical models, lending confidence to the basic parameter dependencies that the analytic models provide. Key parameters are the ratio of the diffusive and thermal boundary layer widths and the relative change in the Coriolis parameter between the two straits that connect the marginal sea to the open ocean. These theories predict a subsurface maximum in the Indonesian throughflow and a branching of the wind-driven inflow into the JES into eastern and western boundary currents, in general agreement with observations.

For the case of a marginal sea connected to the open ocean through a single strait, the focus has been on the circulation induced by cooling in the interior and the resulting exchange with the open ocean. The basin-scale circulation and stratification can be very sensitive to small-scale mixing near the boundaries. Analytic models and a parameterization of eddy fluxes over a sloping bottom have also been developed to understand what controls the properties of water masses formed within the marginal sea and the exchange rate with the open ocean. It is also found that essentially all of the downwelling within the marginal sea is concentrated within narrow boundary layers near the side walls, even when all of the surface forcing is located in the basin interior. The width of these boundary layers depends on the internal deformation radius and the horizontal Prandtl number, indicating that both the downwelling limb of the thermohaline circulation and the large-scale circulation in the marginal sea depend closely on mixing near topography at scales smaller than the deformation radius.

IMPACTS FOR SCIENCE

These results demonstrate how the exchange between marginal seas and the open ocean depends strongly on the physical processes with the marginal sea. This not only points to the importance of

buoyancy-forcing and a proper representation of boundary currents and small-scale mixing near boundaries for basin-scale models, but also suggests that care must be taken in the specification of the strait transports for regional models of marginal seas. The regions of strong air-sea exchange or small-scale mixing predicted by these models are also regions of strong upper ocean temperature gradients and vertical motions and, hence, are important regions for biological productivity.

RELATIONSHIP TO OTHER PROGRAMS

The physical understanding provided by these simple models focuses attention on the key processes that must be properly represented in predictive models of these regions. This should allow for better predictions of the ocean currents in such marginal seas and their sensitivity to air-sea exchange.

This study is closely related to the ONR-funded Japan / East Sea program (JES) and the ONR LINKS (Dynamical Linkage of the Asian Marginal Seas) program, which use a combined observational and modeling approach to study the circulation and exchange between the Asian marginal seas and the open ocean. The ONR ASIAEX (Asia Seas International Acoustics Experiment) volume interactions program in the South China Sea also addresses some common issues of marginal sea/open ocean exchange, as does the Circulation Research on the East Asian Marginal Seas (CREAMS) program being jointly supported by Korea, Japan, and Russia. These results are also closely related to the circulation in the Adriatic Sea, the subject of both ONR Adriatic Mesoscale Experiment and the NRL Adriatic Circulation Experiment.

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